

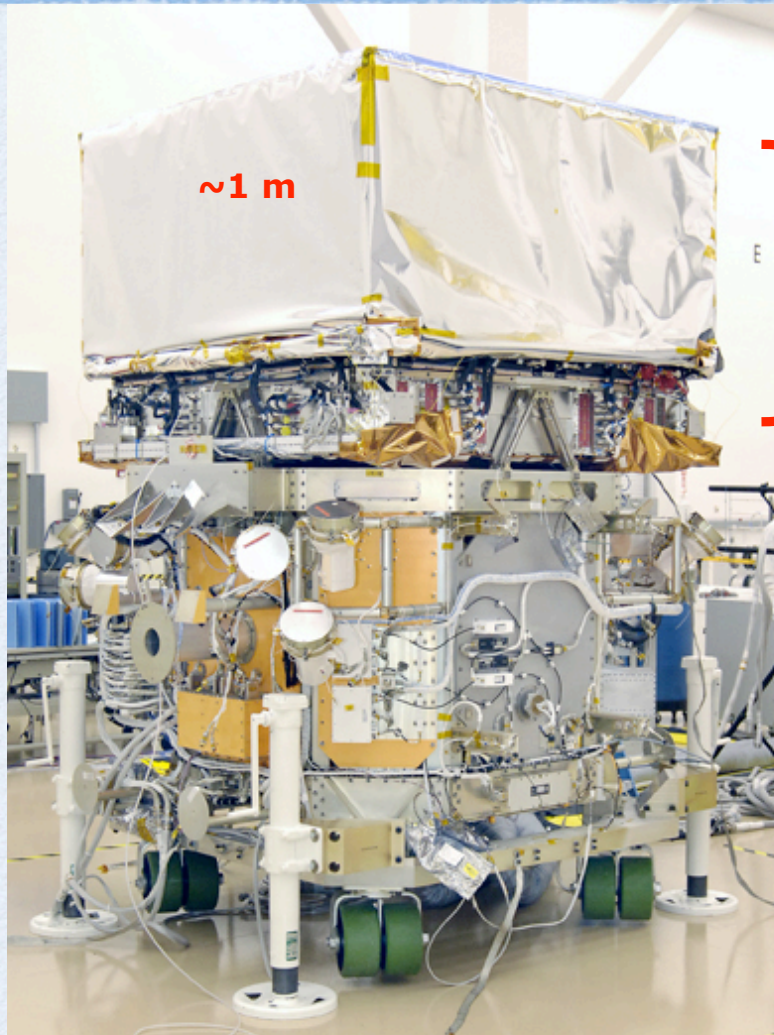
Dark Matter Searches with Fermi



Louis Strigari
KIPAC-Stanford University
INFO11
Santa Fe
7/20/2011



Fermi Observatory

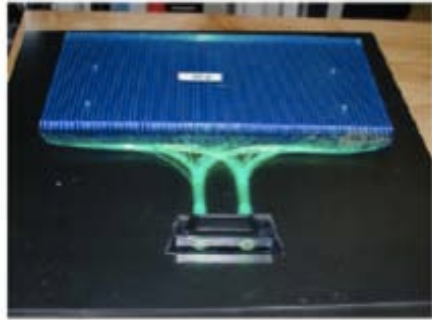


Large Area Telescope (LAT)
* High Energy Gamma Rays
* $20 \text{ MeV} > E > \sim 300 \text{ GeV}$

Spacecraft

Gamma-Ray Burst Monitor
* GRB Detection.
* $10 \text{ KeV} < E < 40 \text{ MeV}$

Fermi-LAT

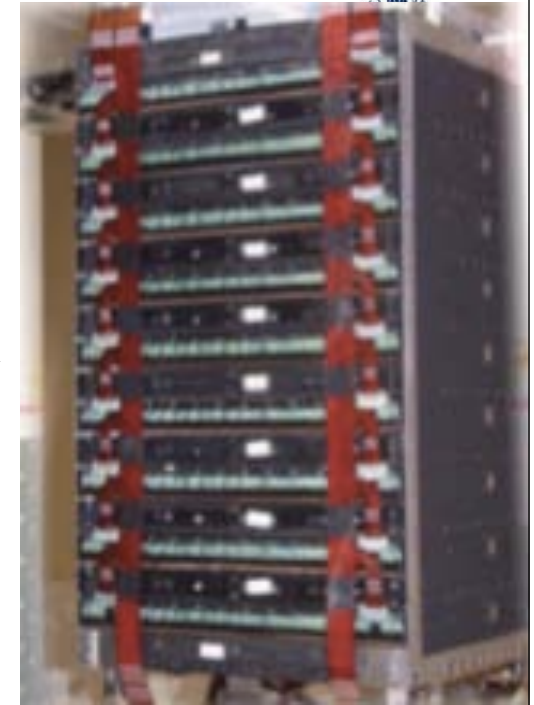
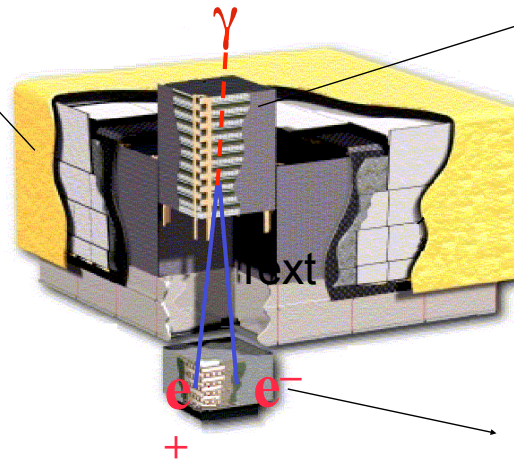


- ACD

- 4% RL
- Segmented (89 plastic scintillator tiles)
- 0.997 efficiency

- Tracker

- Single sided SSD (400 μm , 228 μm)
- W foil interleaved (12x3%RL, 4x18RL)
- 18 xy planes



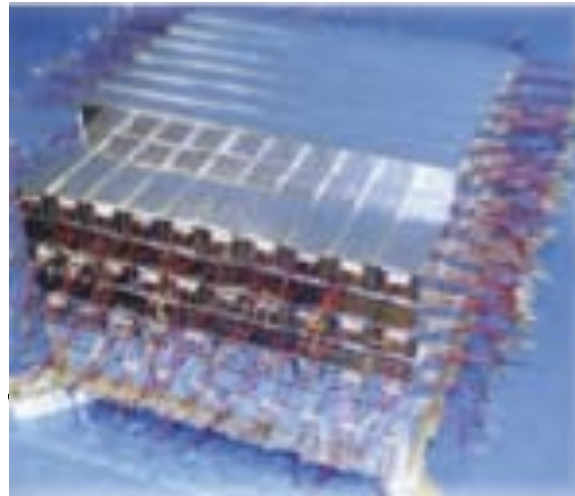
- Calorimeter

- 8.5 R.L.
- 1536 CsI(Tl) crystals (1200 kg)
- Hodoscopic (12x8 layers)



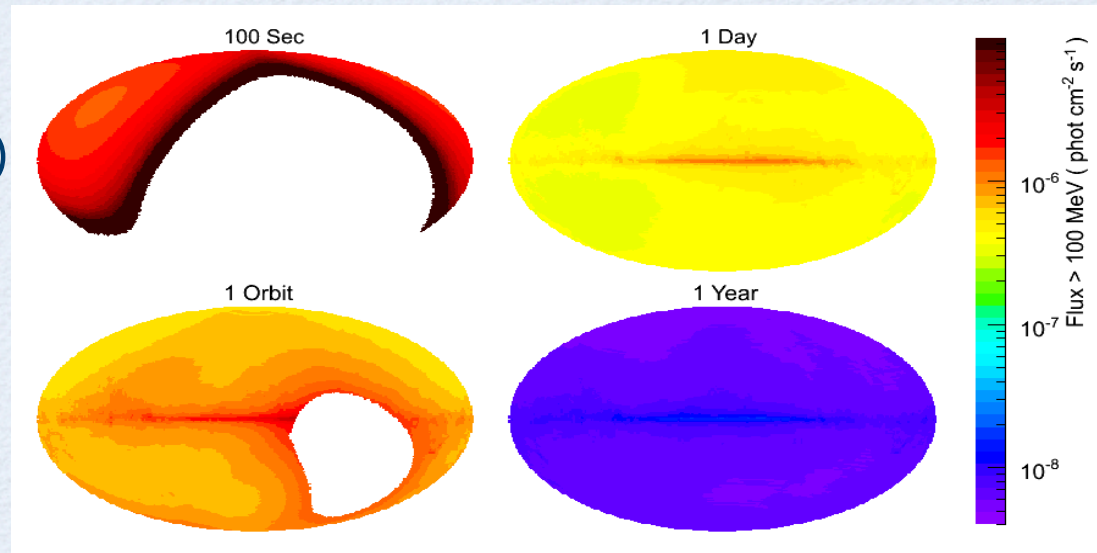
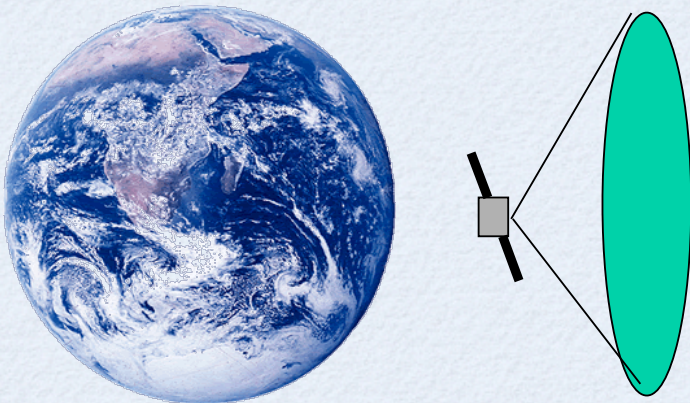
Launch 11.
juni 2008

Nominal
operations:
Aug 4 2008



Operational Modes

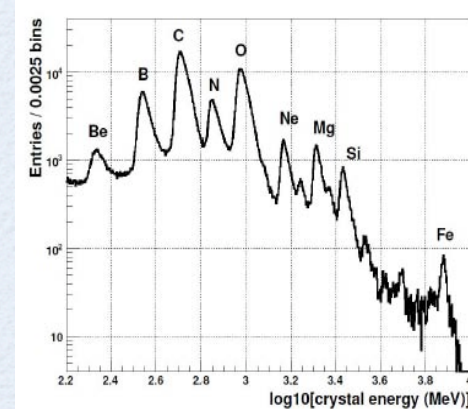
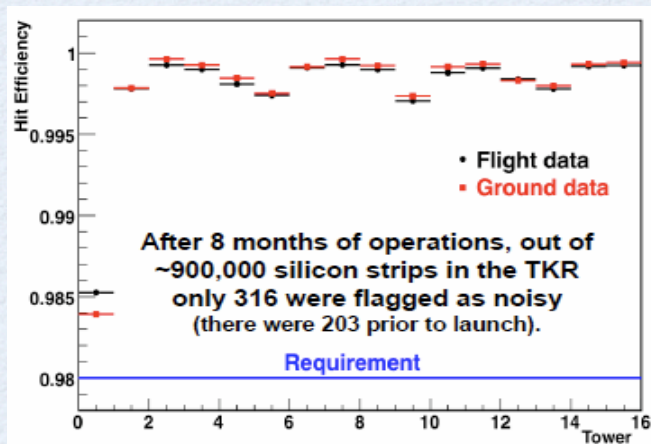
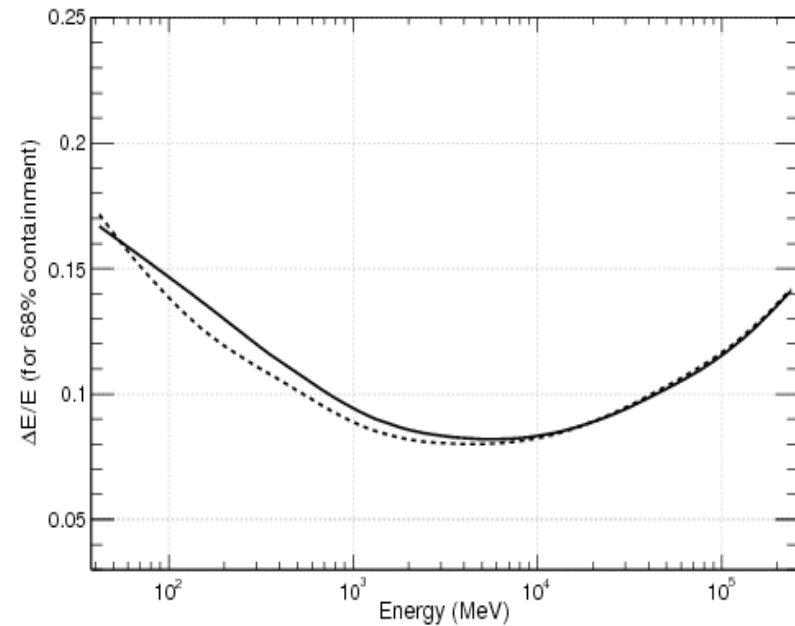
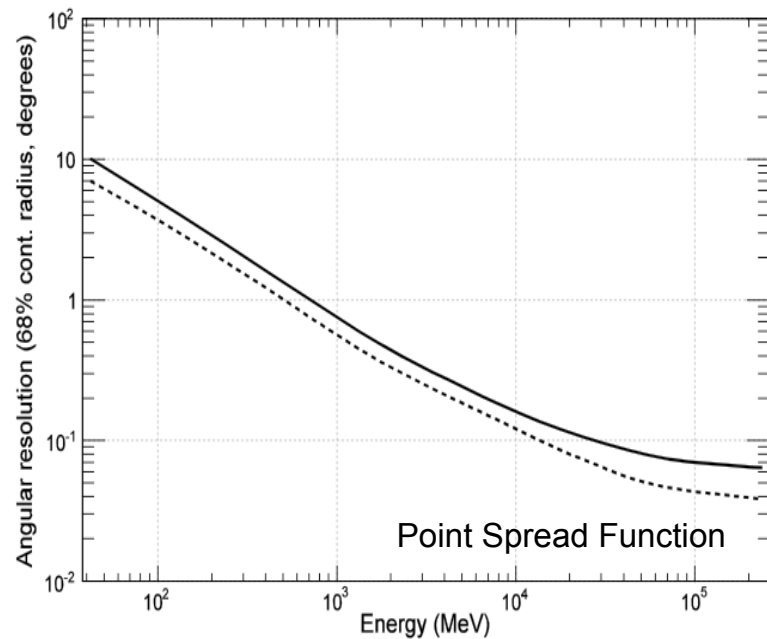
- Sky survey mode
 - Standard operation mode
 - View full sky every 2 orbits
- Targets of opportunity (ToO)
 - Autonomous repoint (GRBs)
 - Slew to keep ToO in FOV
 - Later: ToO proposals



LAT: Wide Field of View $\sim 2.4 \text{ sr}$

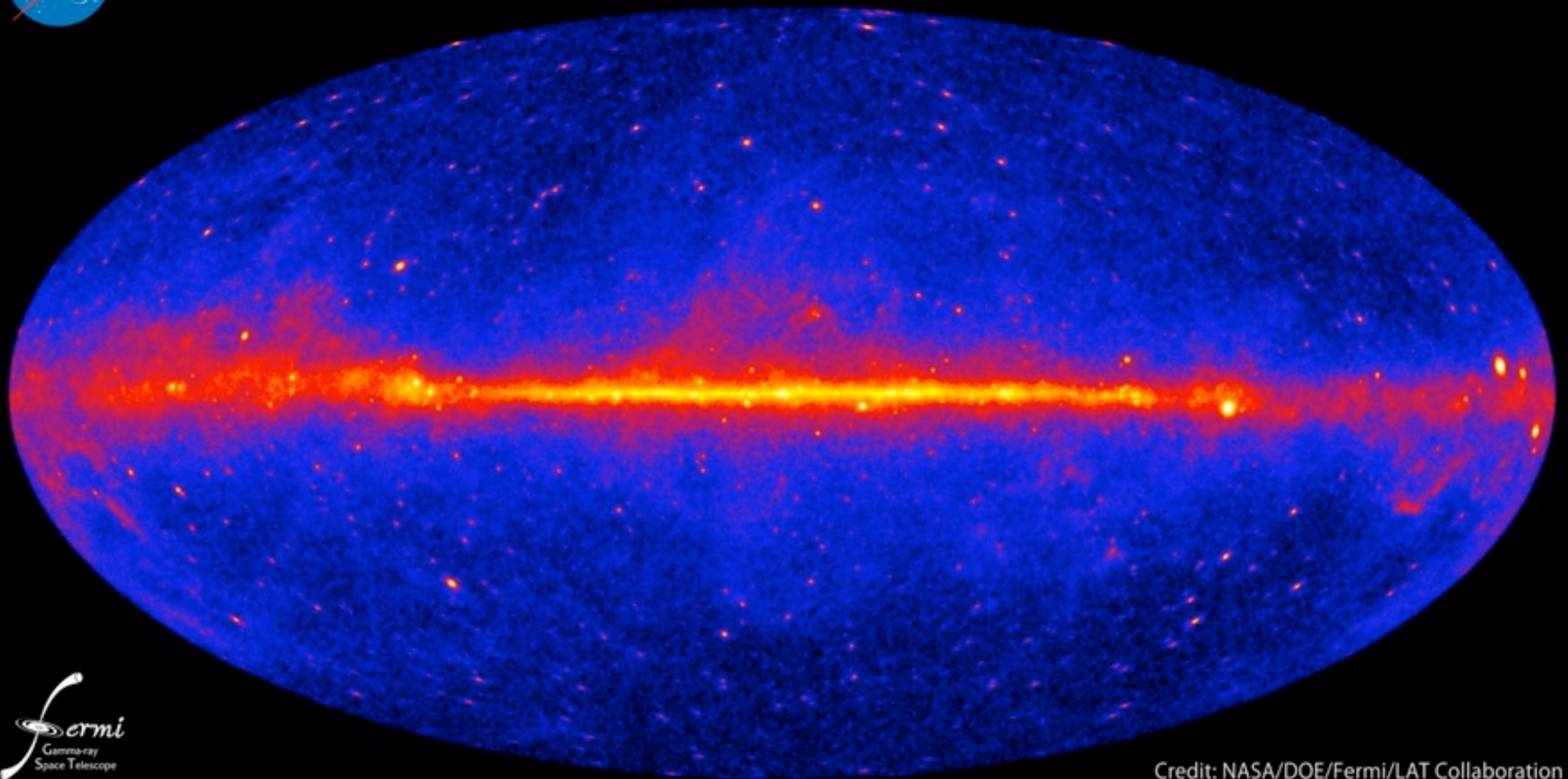
GBM: See almost all of the sky
not occulted by the earth

Detector Performance



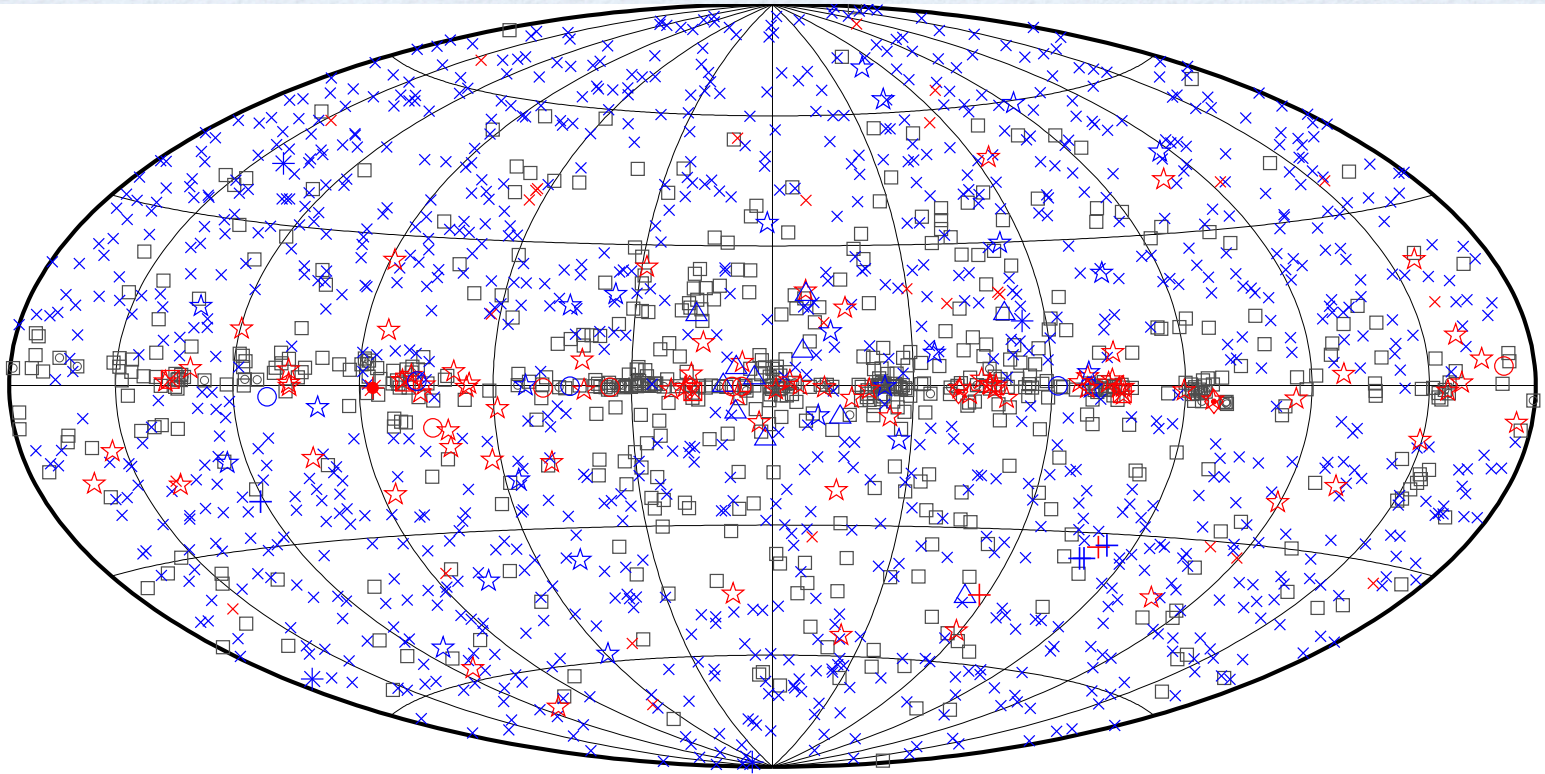


Fermi two-year all-sky map



Credit: NASA/DOE/Fermi/LAT Collaboration

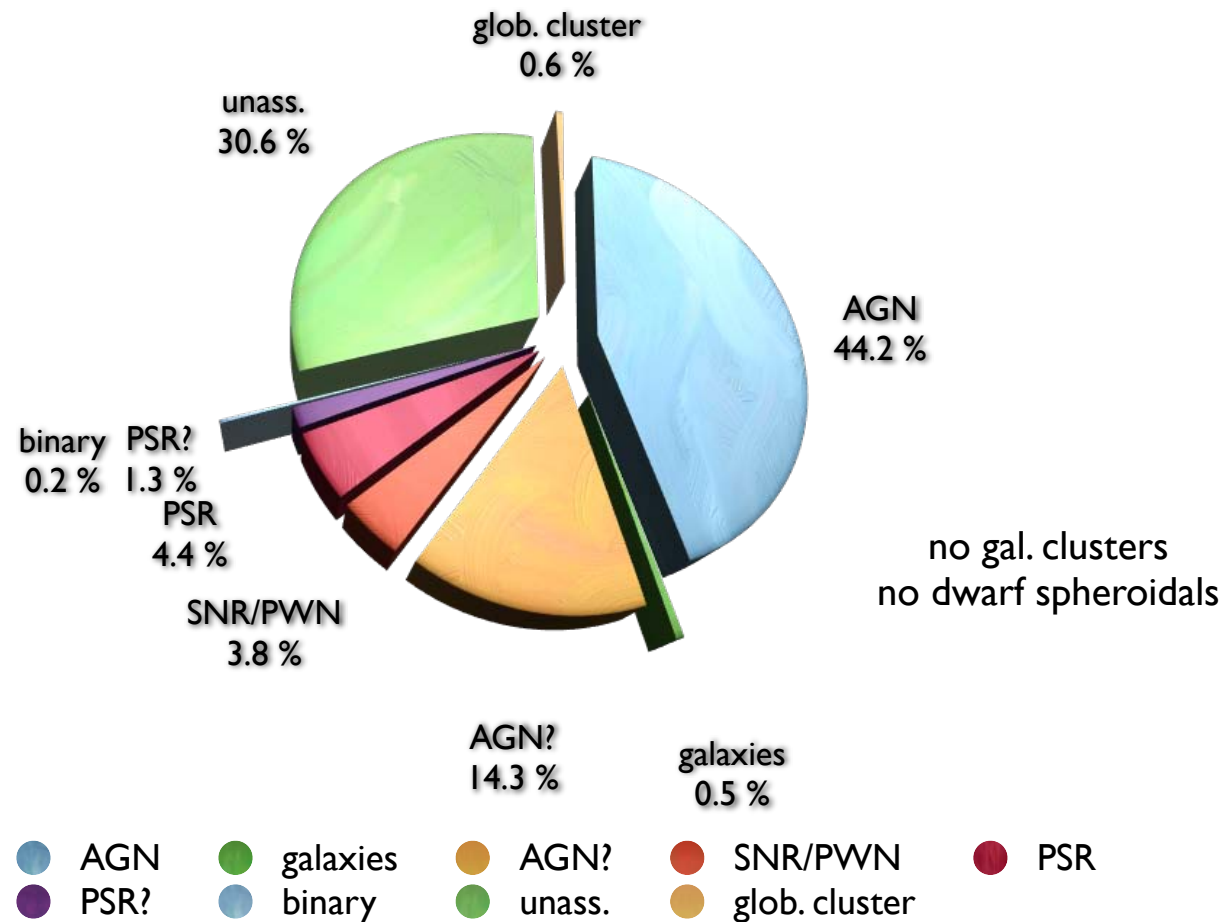
2 year source catalog



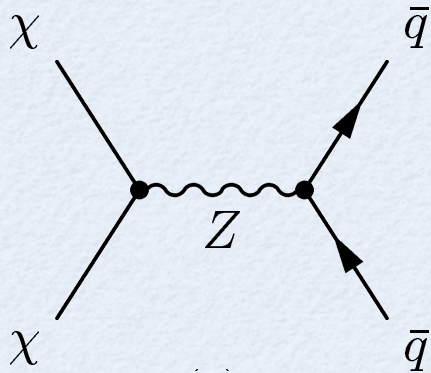
- | | | |
|------------------|--|--------------------|
| □ No association | ◻ Possible association with SNR or PWN | |
| × AGN | ☆ Pulsar | △ Globular cluster |
| * Starburst Gal | ◇ PWN | ⊠ HMB |
| + Galaxy | ○ SNR | ★ Nova |

2 year source catalog

2FGL associations

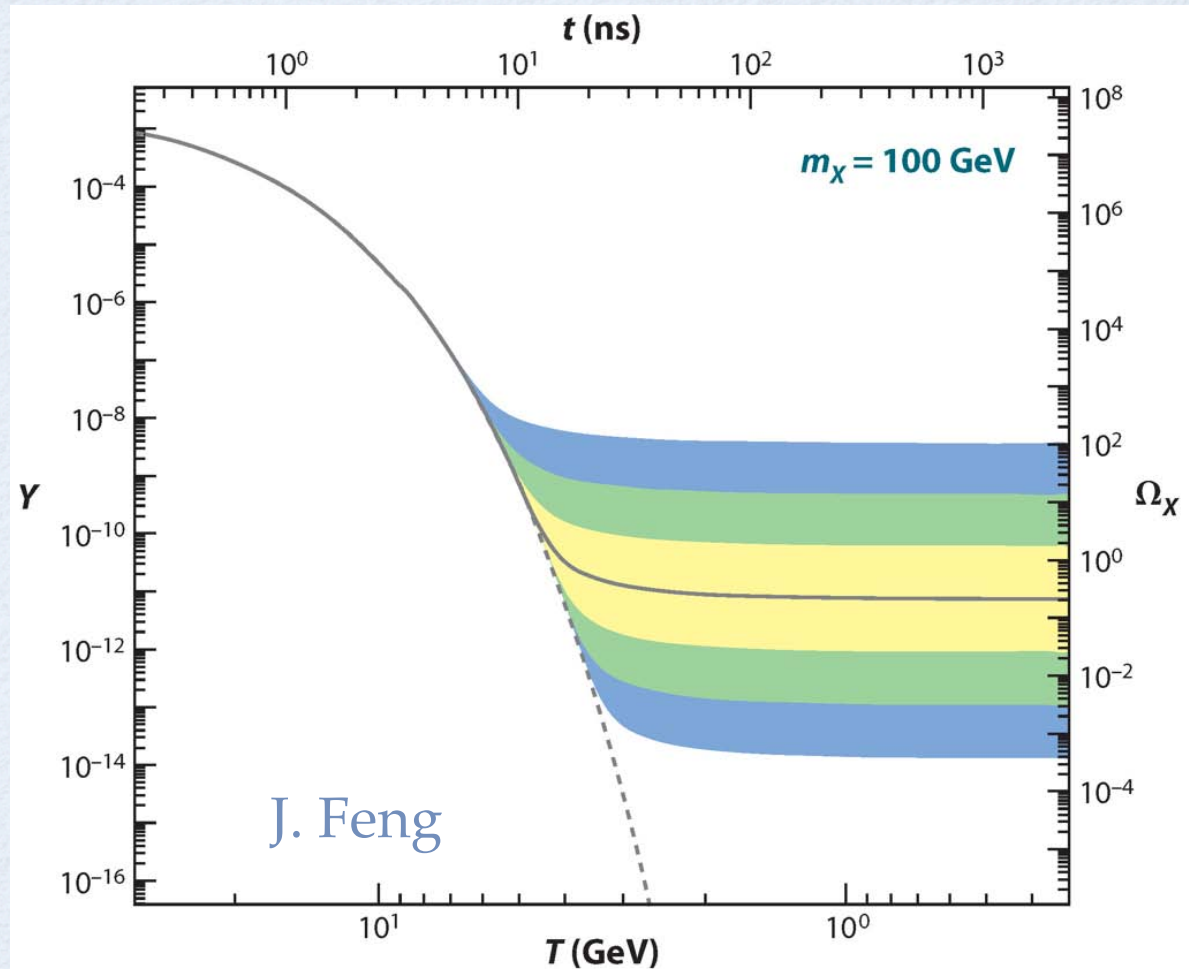


Particle Dark Matter: WIMPs

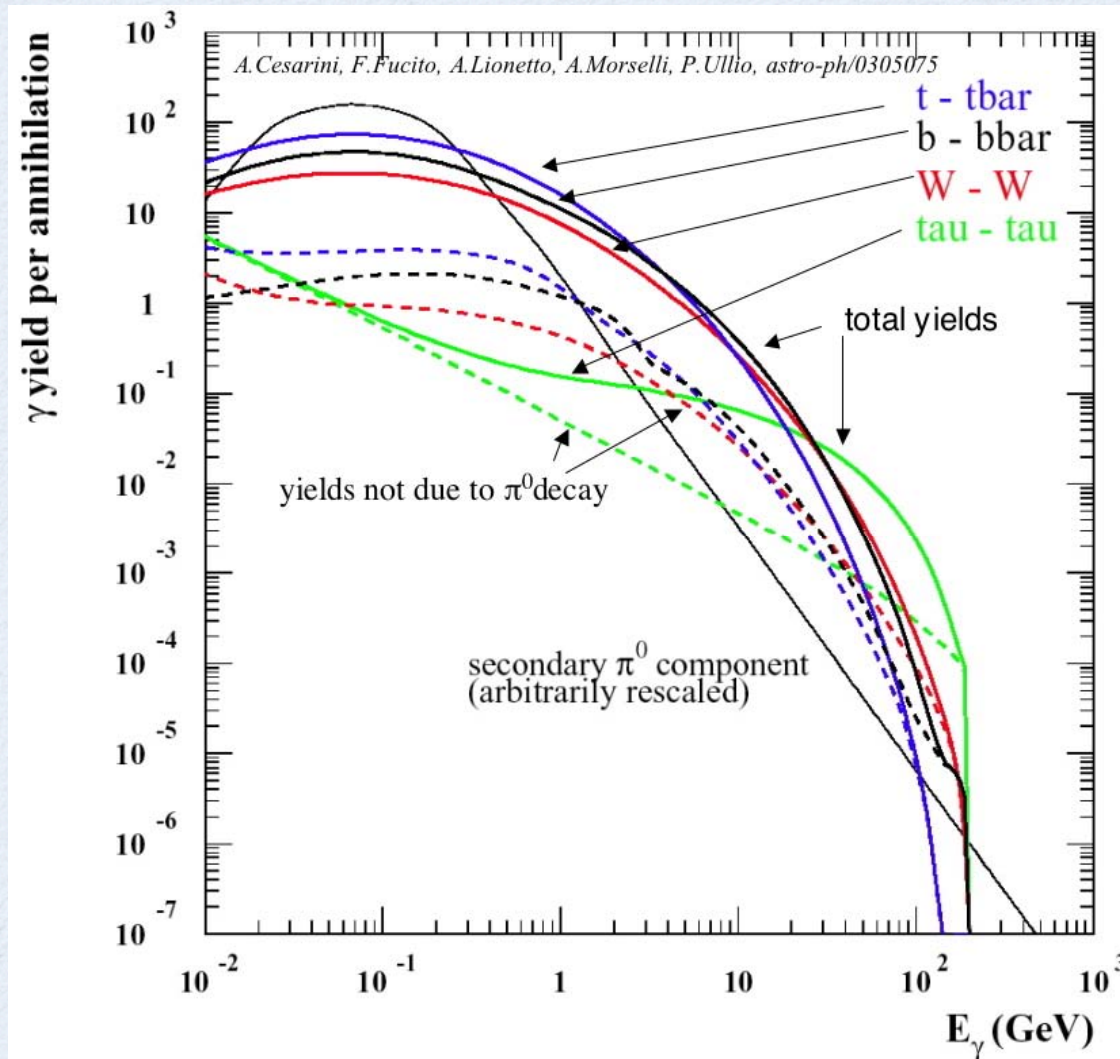


$$\langle\sigma v\rangle \sim 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$$

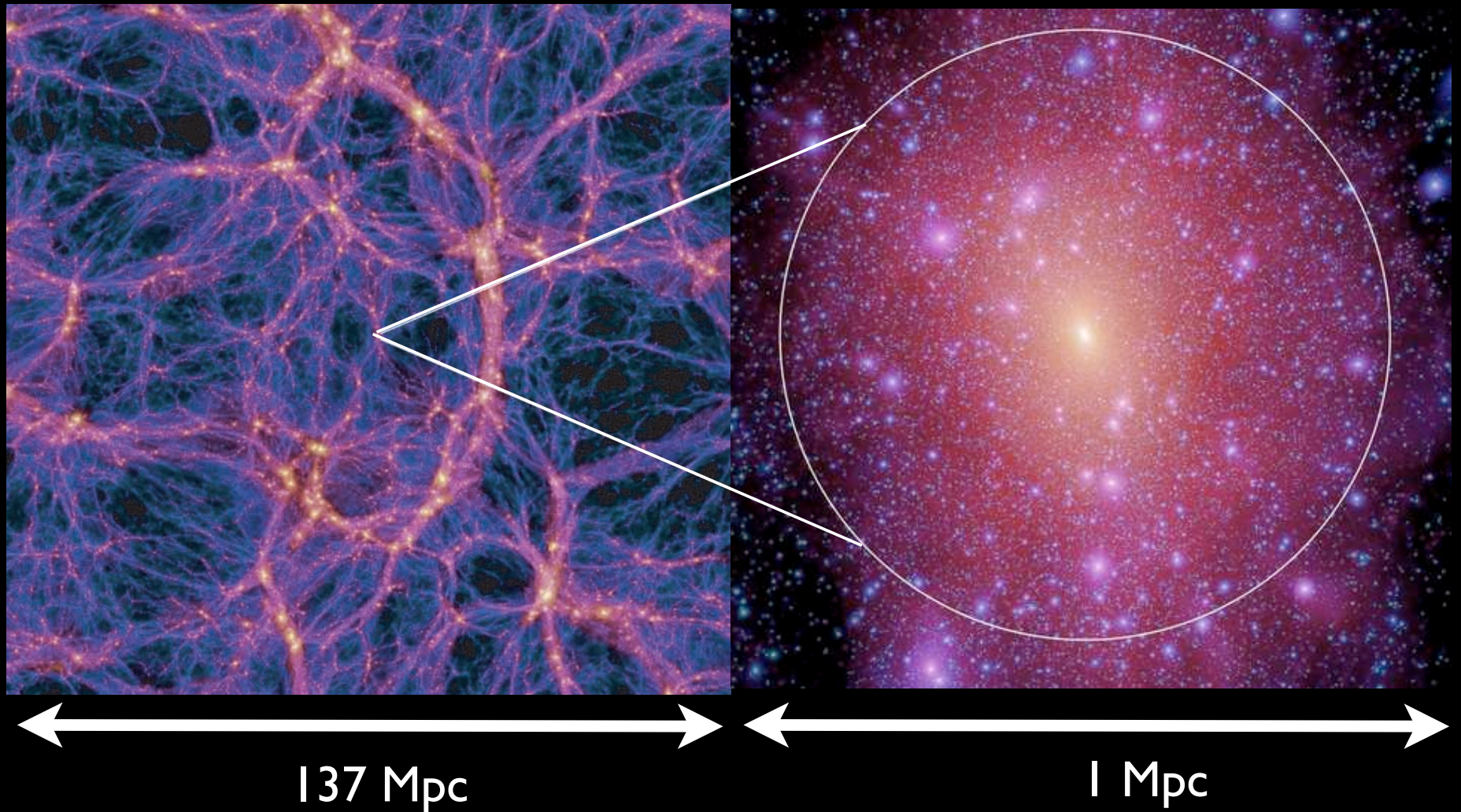
e. g. Zeldovich 1965, Chiu 1966



How to find the dark matter

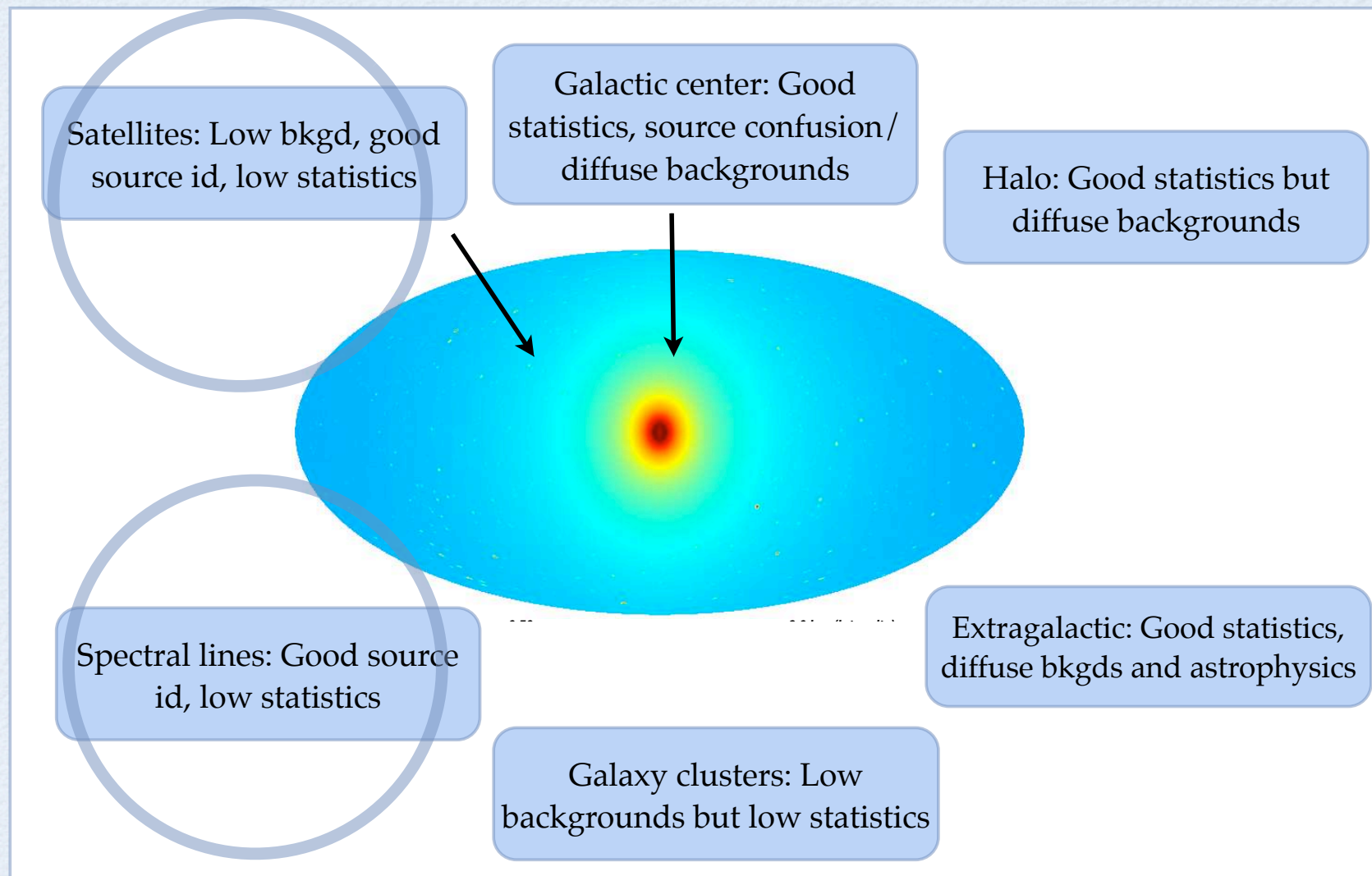


Where is the dark matter?



Springel et al. 2008

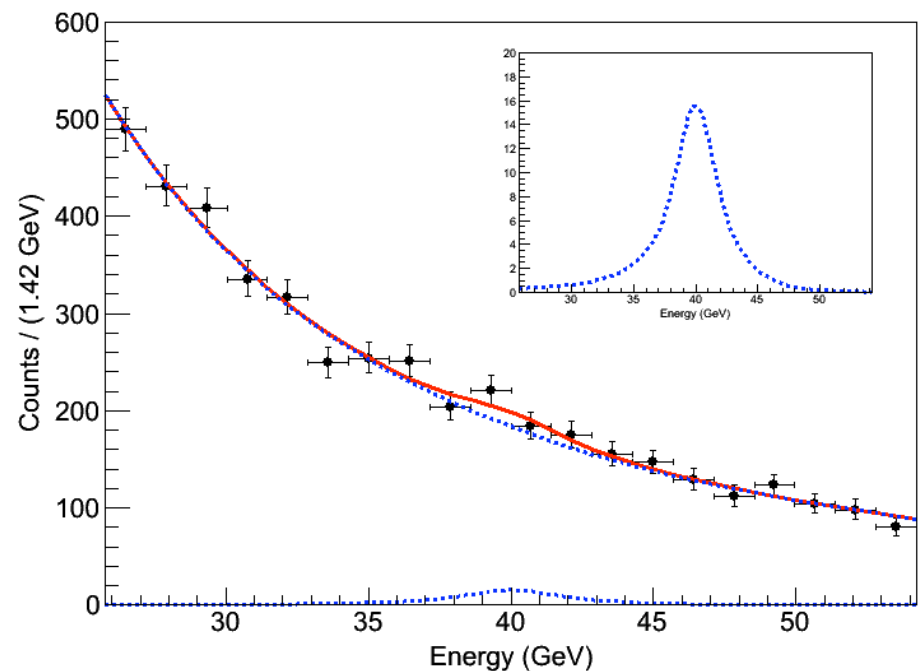
WIMP annihilation: Search Strategies



Fermi Constraints on Lines from Galaxy

- ▶ Limits obtained in the energy range 30-200 GeV
- ▶ Search region $b > 10$ degrees and a region right around the GC
- ▶ 11 months of data
- ▶ Obtained cross section upper limits of order $10^{-27} \text{ cm}^3 \text{ s}^{-1}$

$$L(\bar{E}|f, \Gamma) = \prod_{i=0}^{n_{tot}} f \cdot S(E_i) + (1 - f) \cdot B(E_i, \Gamma)$$

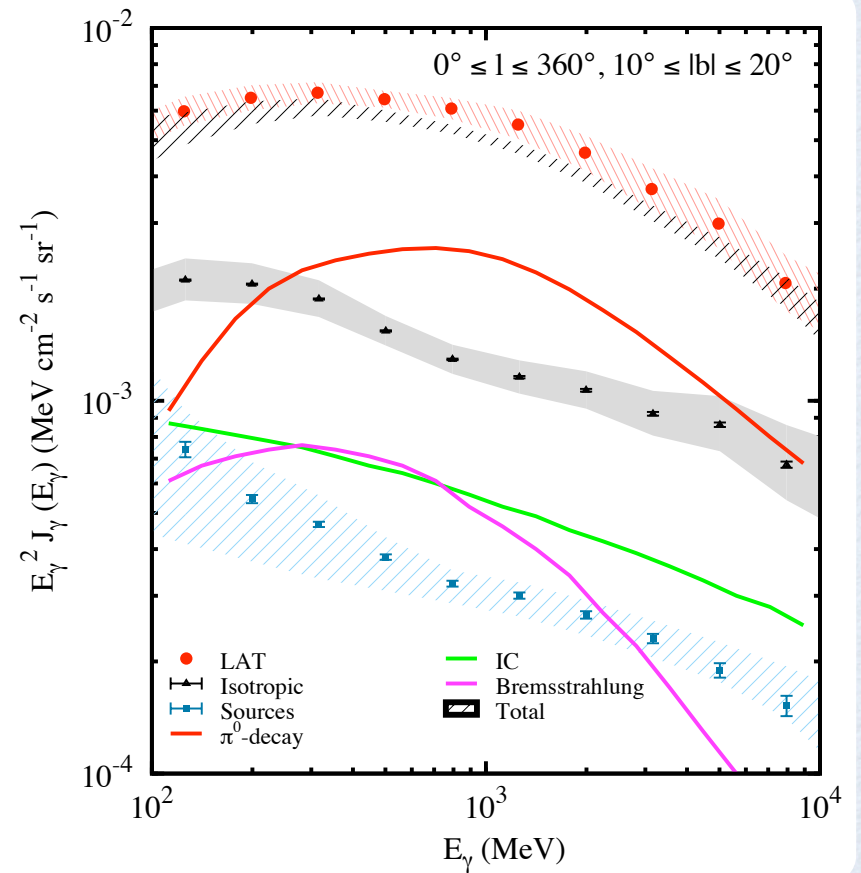
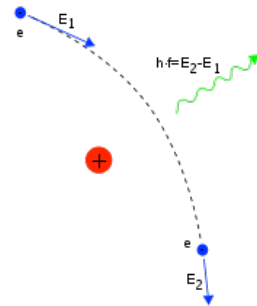


Phys.Rev.Lett.104:091302,2010

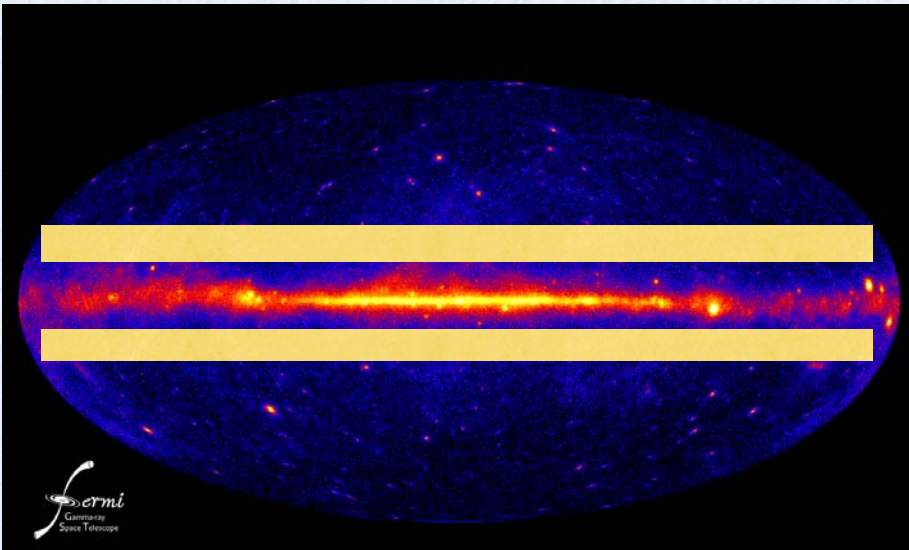
Diffuse Emission



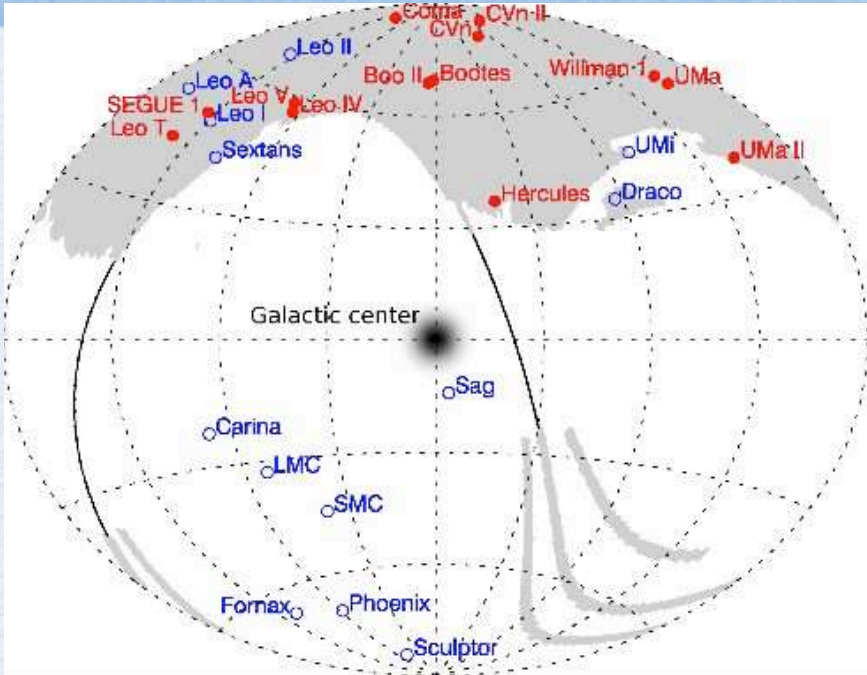
$$\pi^0 \rightarrow \gamma\gamma$$



Fermi collaboration, PRL 2009



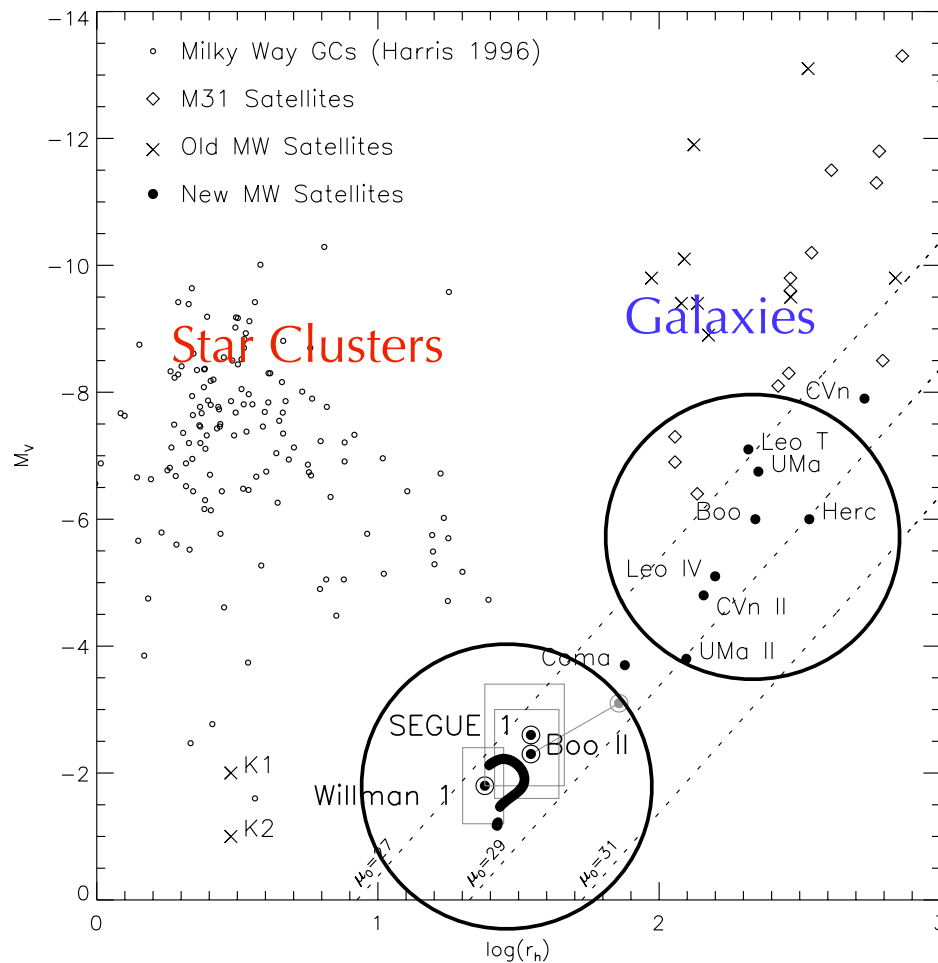
Milky Way Satellite Galaxies



- ▶ Old stars
- ▶ Dark-matter dominated
- ▶ Same central dark matter densities [Strigari et al. Nature 2008)

[Mateo ApJ 1993; Gilmore et al. ApJ 2007]

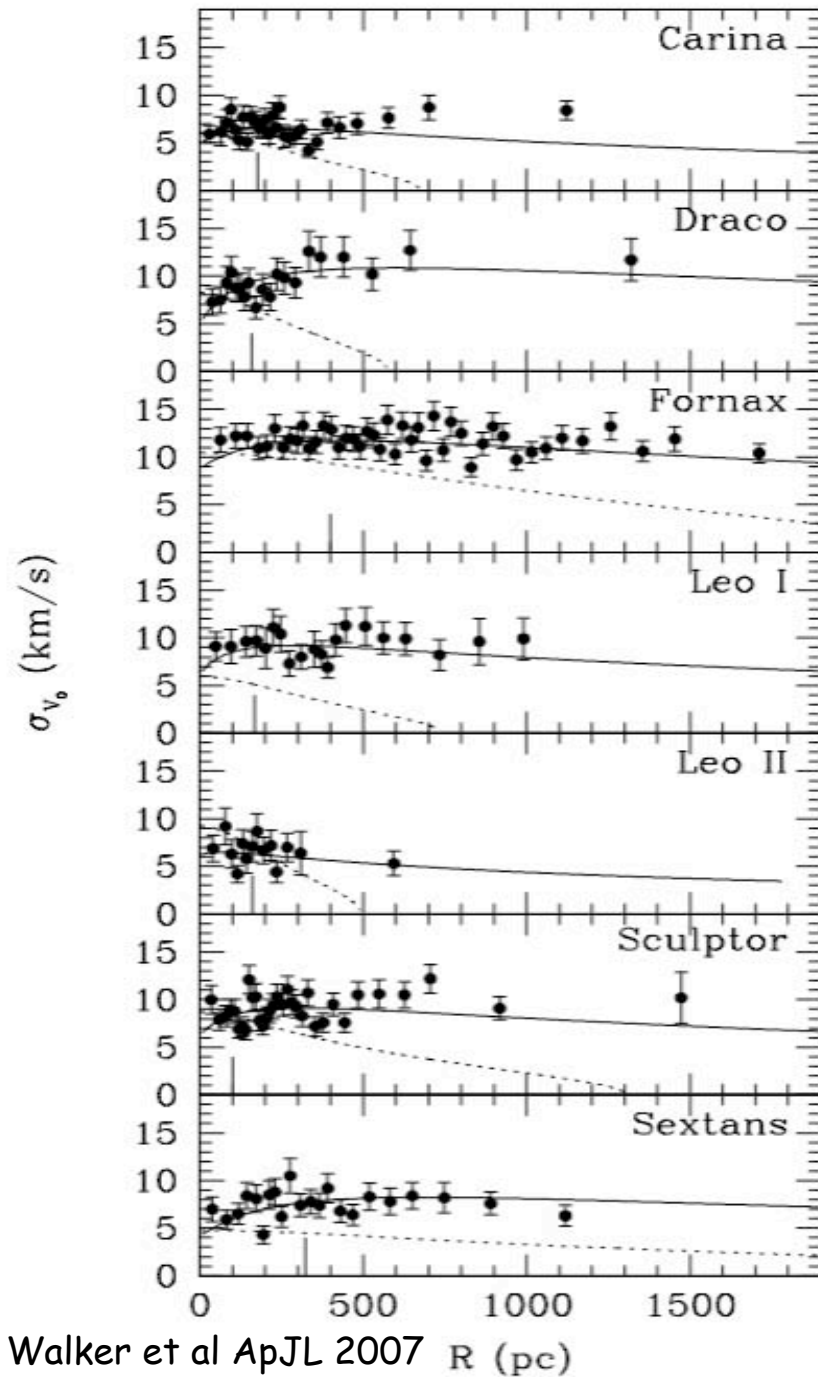
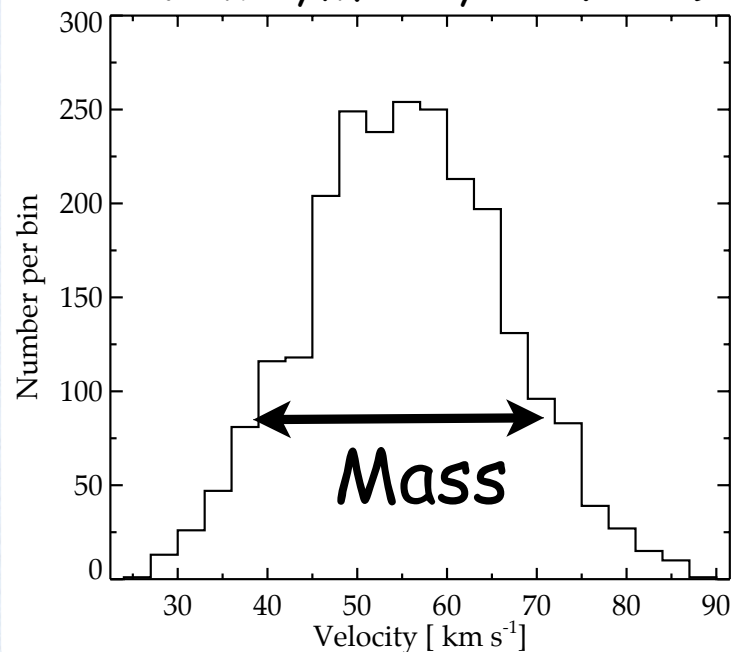
Low mass stellar systems



Galaxies!

Evidence for Dark Matter!

Walker, Mateo, et al. 2009



Walker et al ApJL 2007

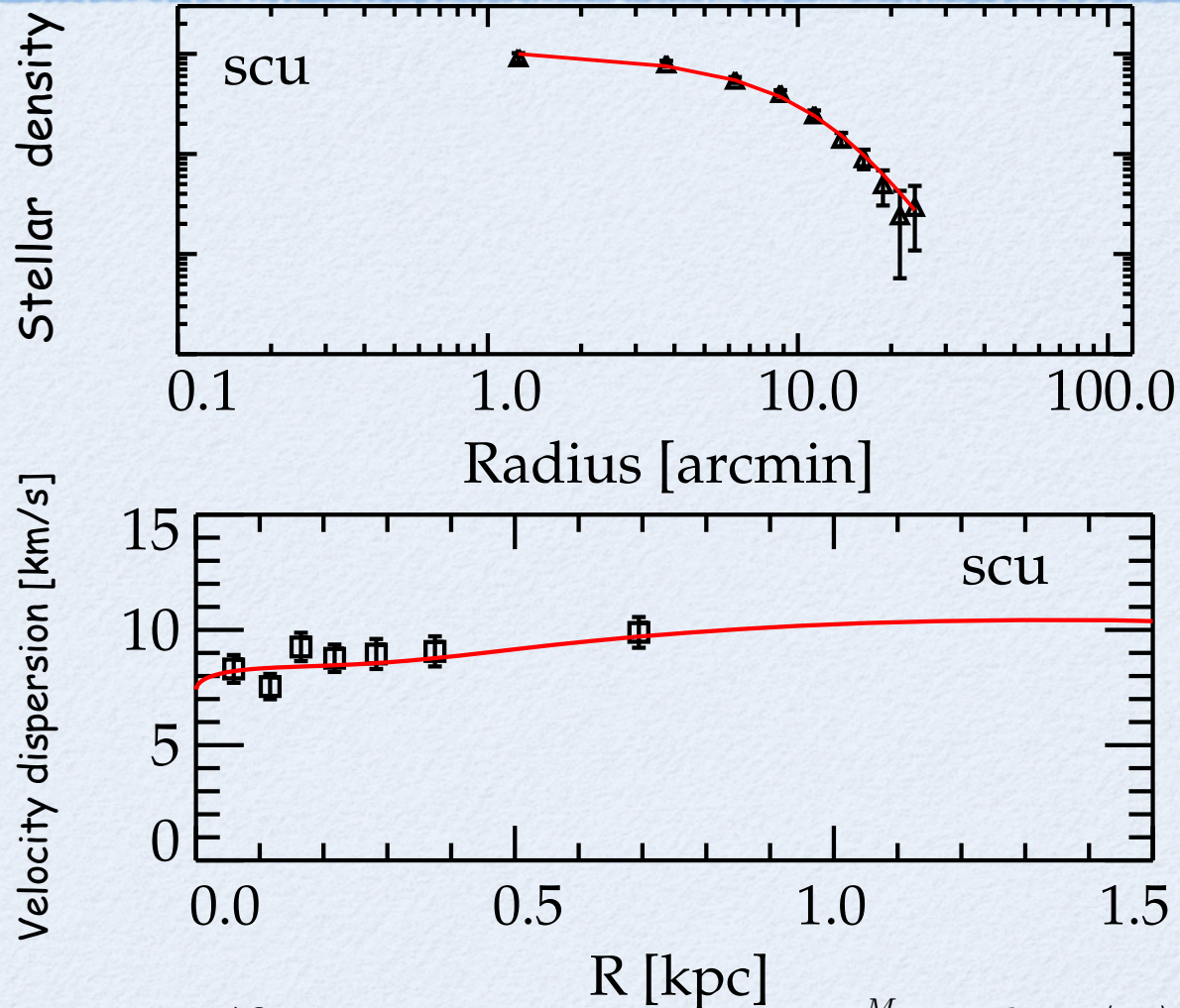
Kinematics: More detailed look

- ★ Model both the stellar and the dark matter distribution
- ★ Statistics of stellar orbits (velocity anisotropy)
- ★ Assume hydrostatic equilibrium, determine mass
- ★ **Warning!**: acceptable solutions don't guarantee consistent distribution function

$$\mathcal{L}(\mathcal{A}) \equiv P(\{v_i\}|\mathcal{A}) = \prod_{i=1}^n \frac{1}{\sqrt{2\pi(\sigma_{los,i}^2 + \sigma_{m,i}^2)}} \exp\left[-\frac{1}{2} \frac{(v_i - u)^2}{\sigma_{los,i}^2 + \sigma_{m,i}^2}\right]$$

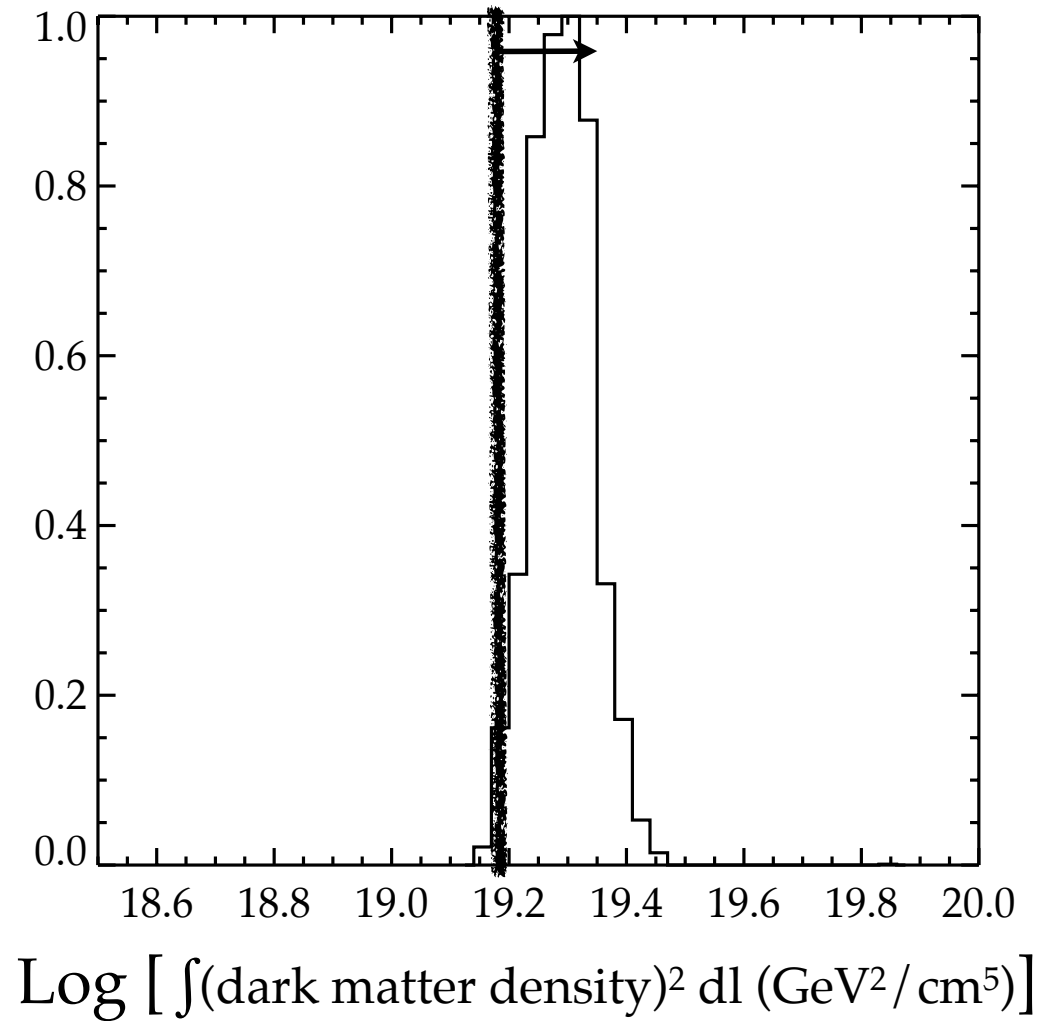
WIMPs in satellite galaxies

Strigari, Frenk, White, MNRAS 2010

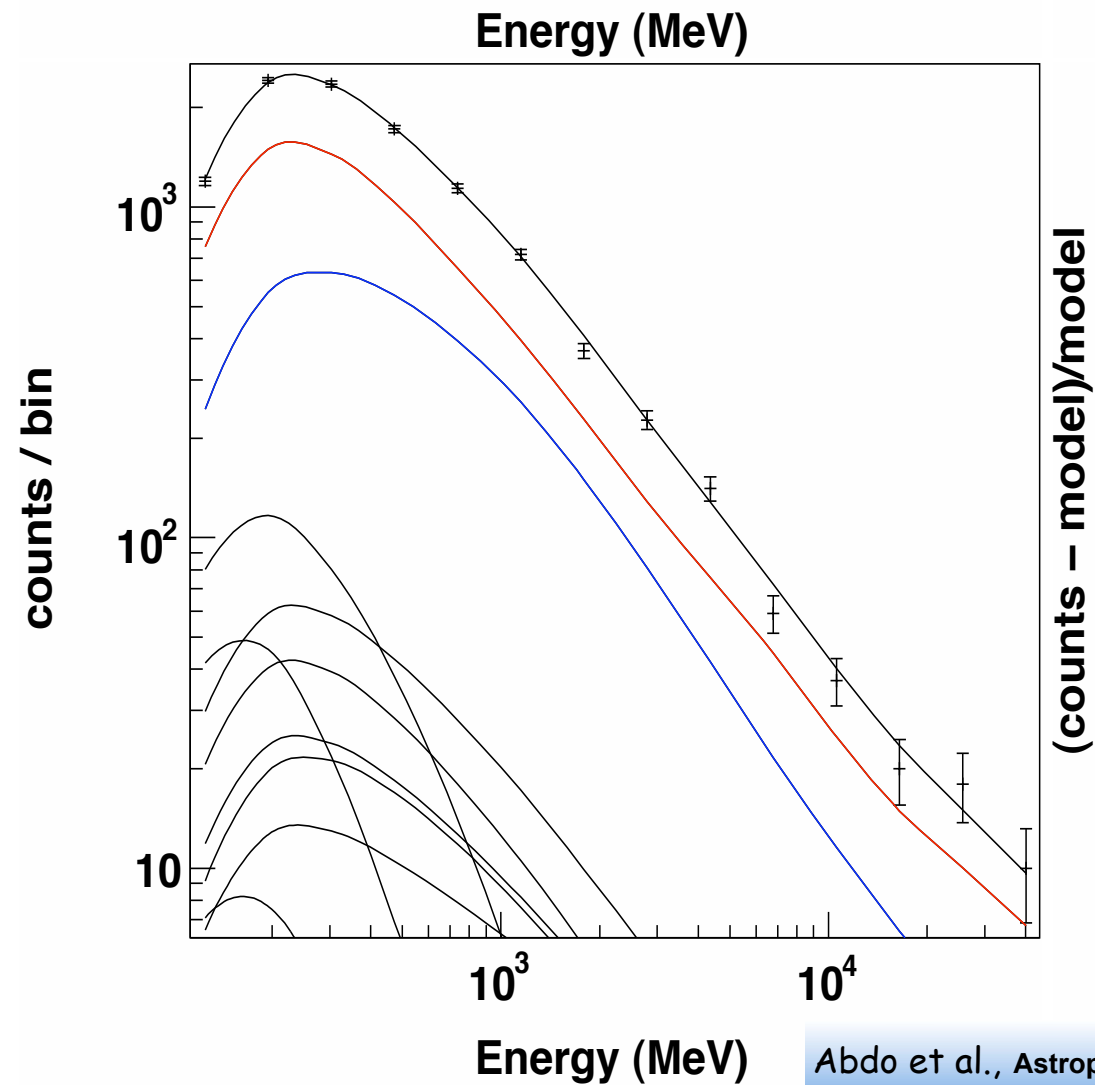


$$\text{Flux} = \left\{ \int_0^{\Delta\Omega} \left\{ \int_{\text{LOS}} \rho^2[r(\theta, \mathcal{D}, s)] ds \right\} d\Omega \right\} \left\{ \int_{E_{\text{th}}}^{M_\chi} \sum_i \frac{dN_{\gamma,i}}{dE} \frac{\langle\sigma v\rangle_i}{M_\chi^2} dE \right\}$$

Best fitting dark matter distribution

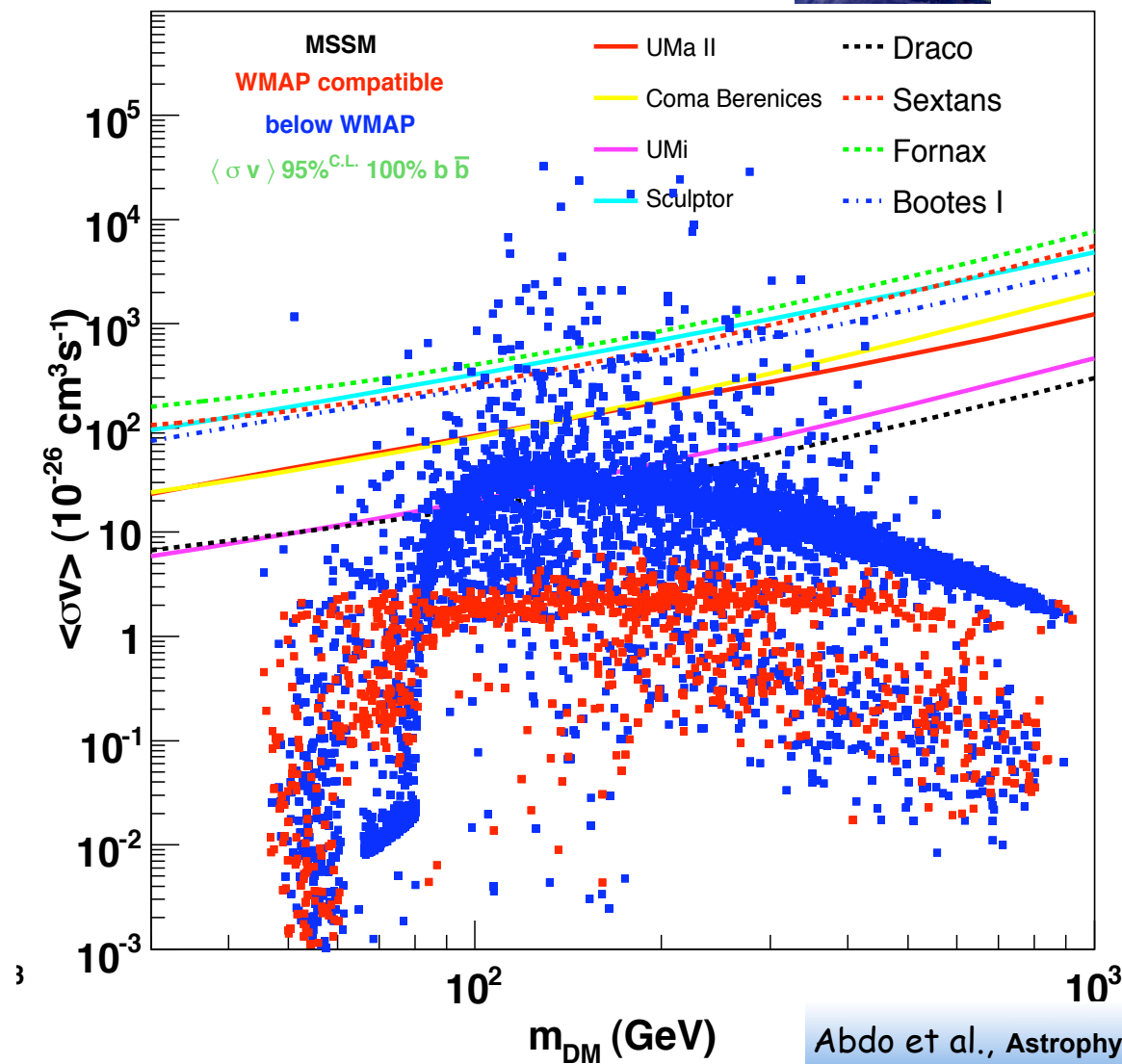


Fermi Source Modeling



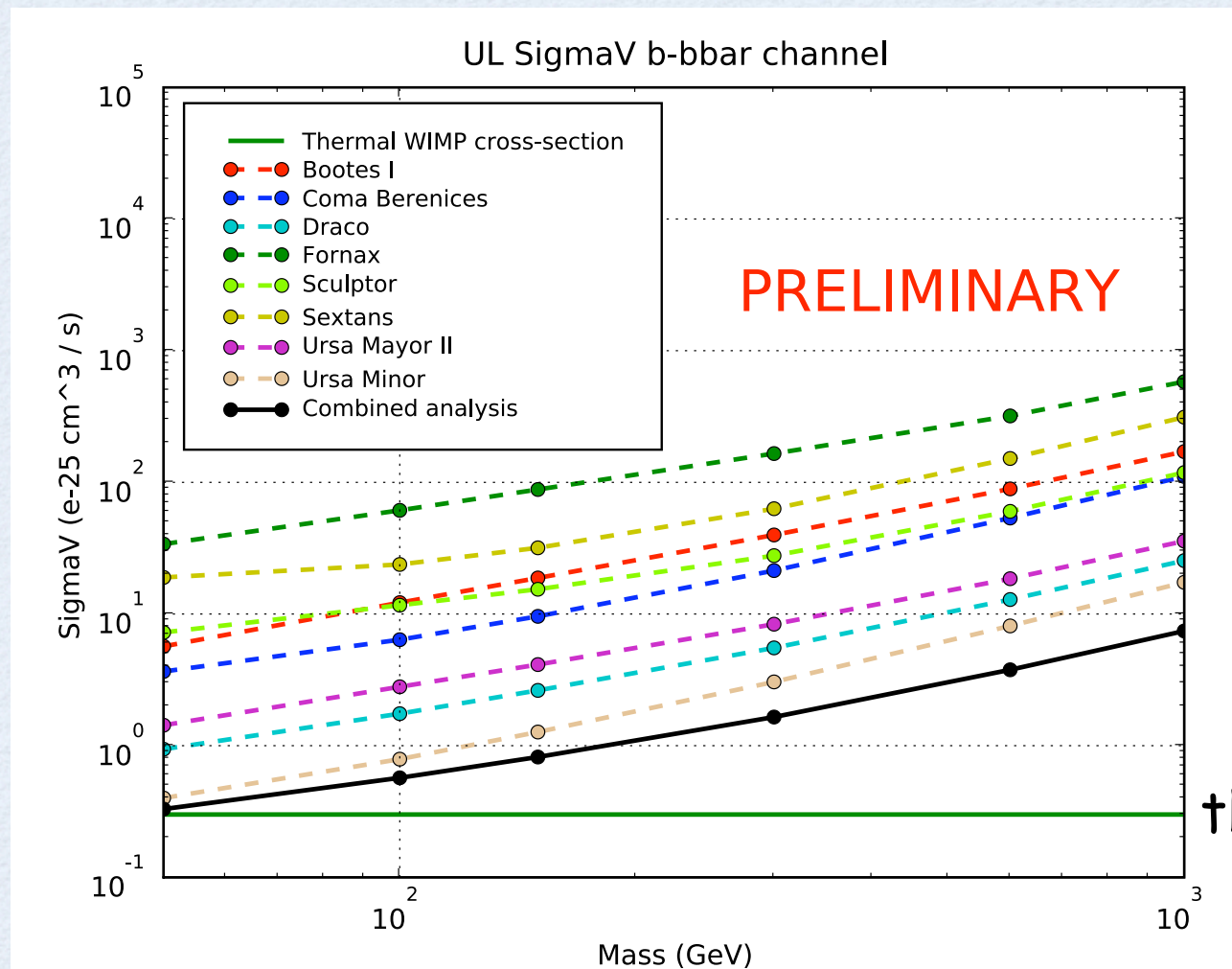
Abdo et al., *Astrophys.J.* 712 (2010) 147-158

FERMI



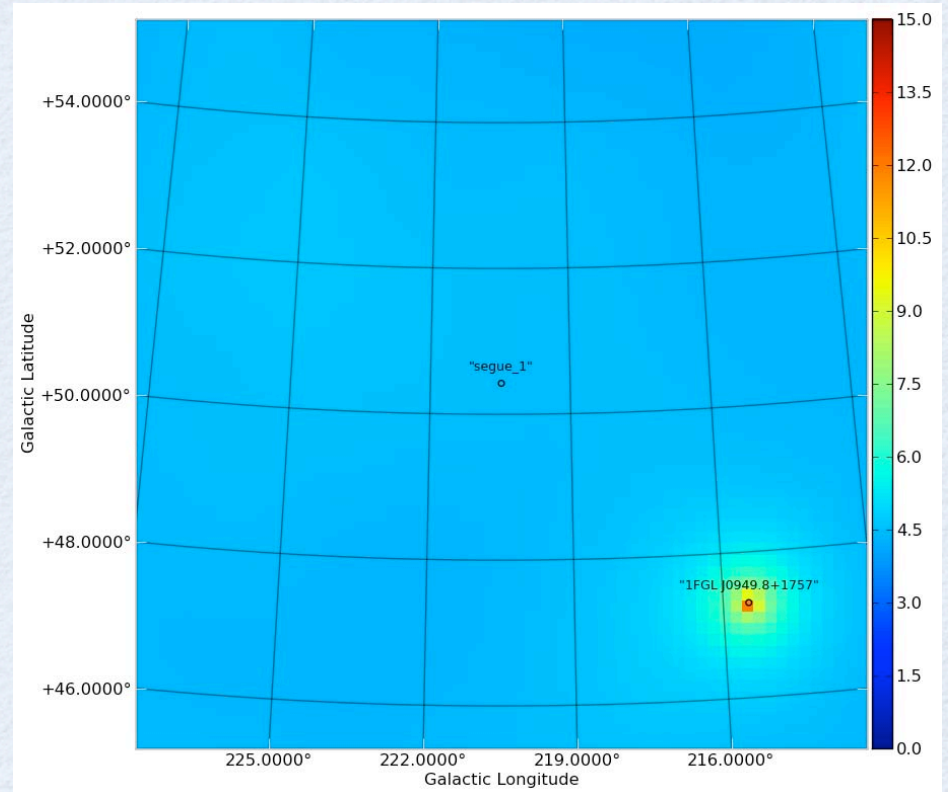
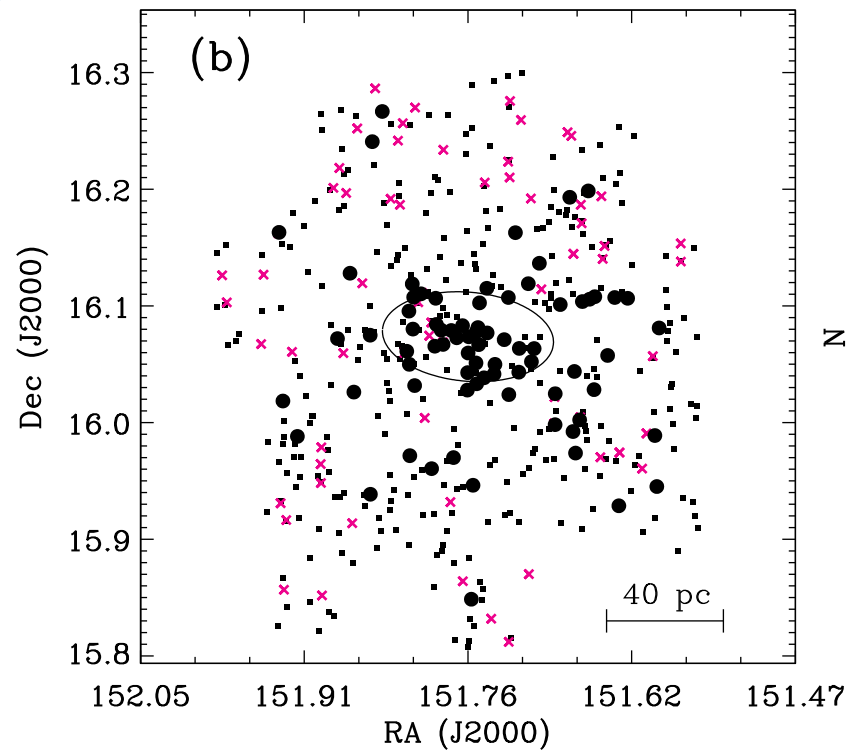
Abdo et al., Astrophys.J. 712 (2010) 147-158

Stacked Satellite Search

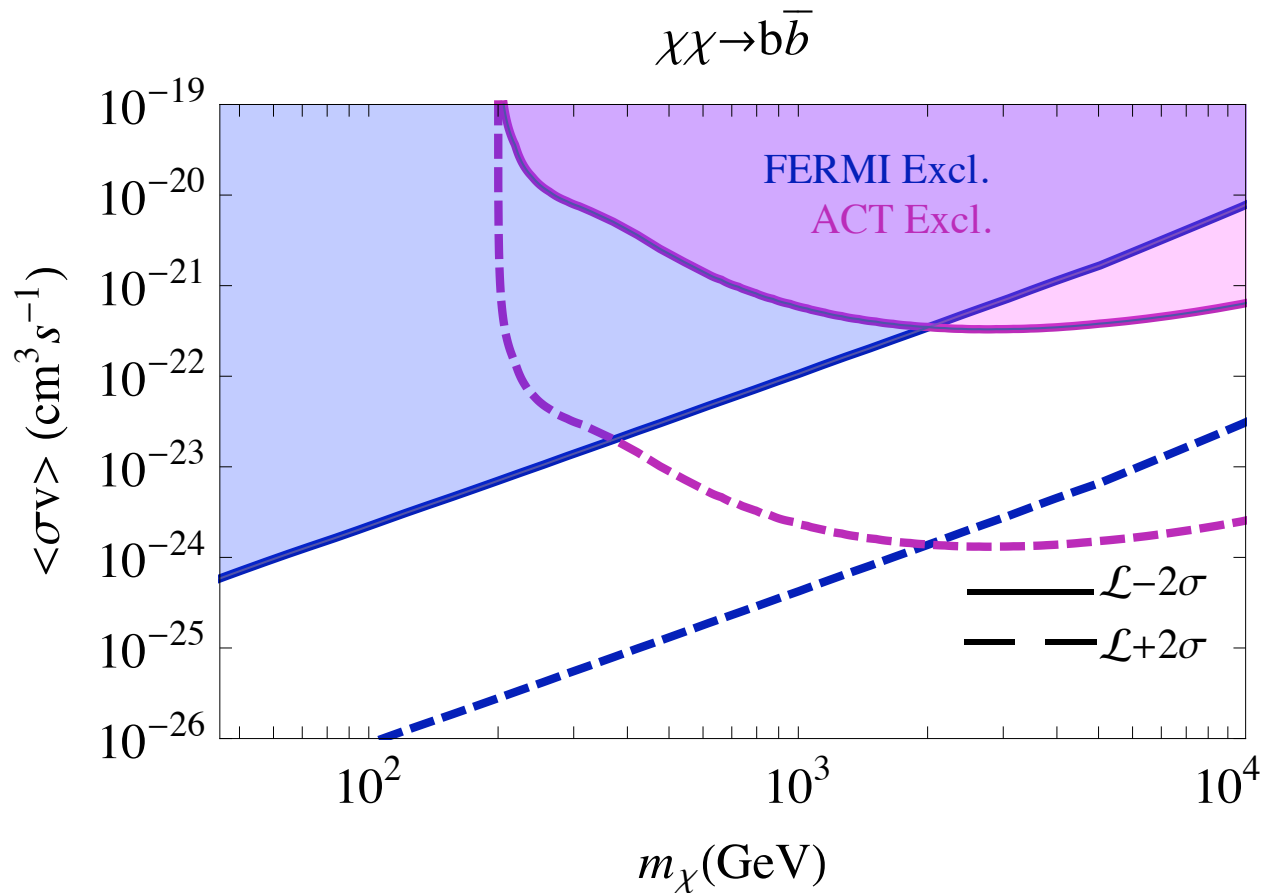


Llena Garde for Fermi-Lat Collaboration [arXiv:1102.5701]

Segue 1: The Darkest Galaxy

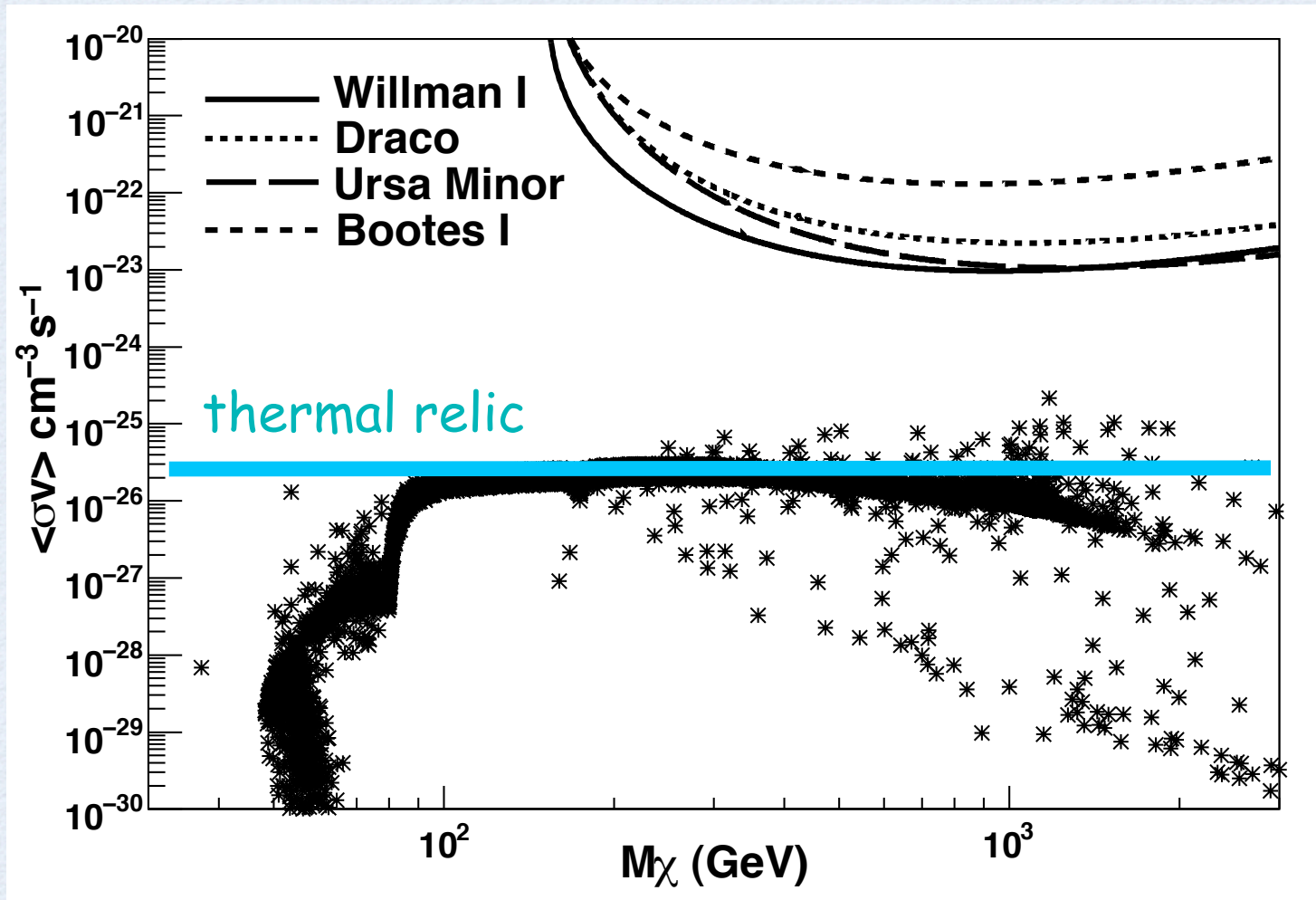


Gamma-ray limits: Segue 1



Essig, Sehgal, Strigari, Simon, Geha, PRD 2010

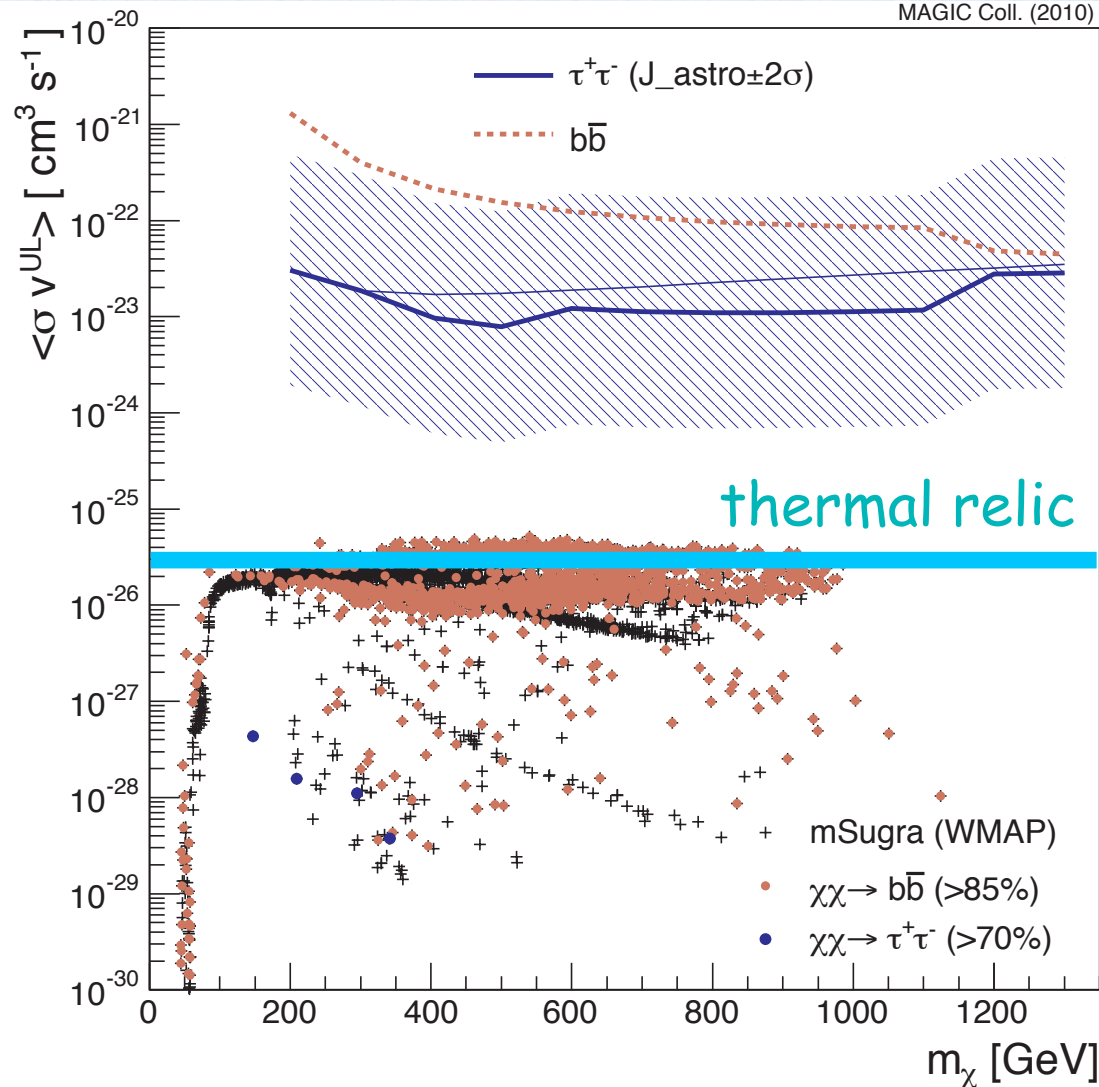
VERITAS



MAGIC



MAGIC Coll. (2010)



Projected limits

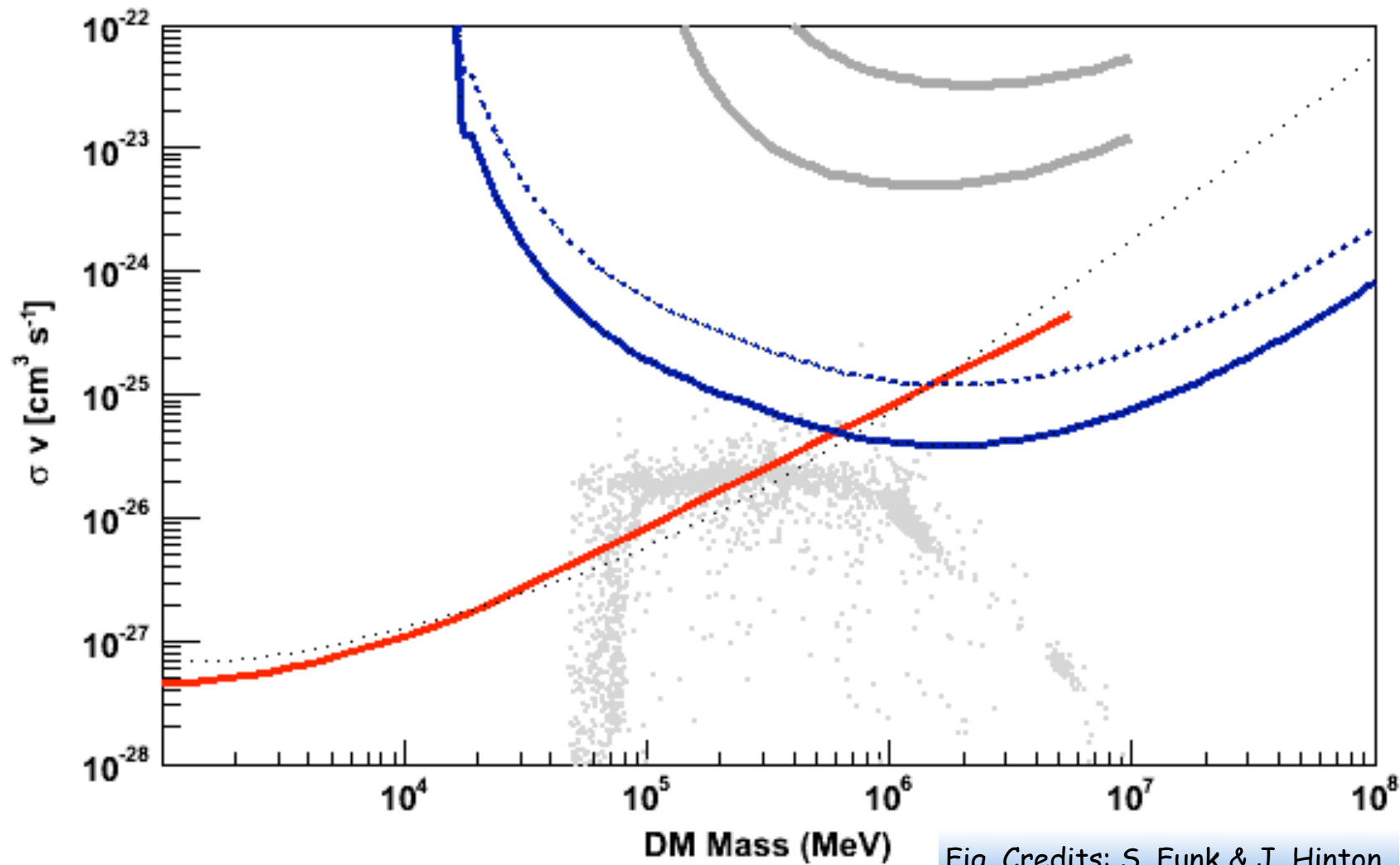
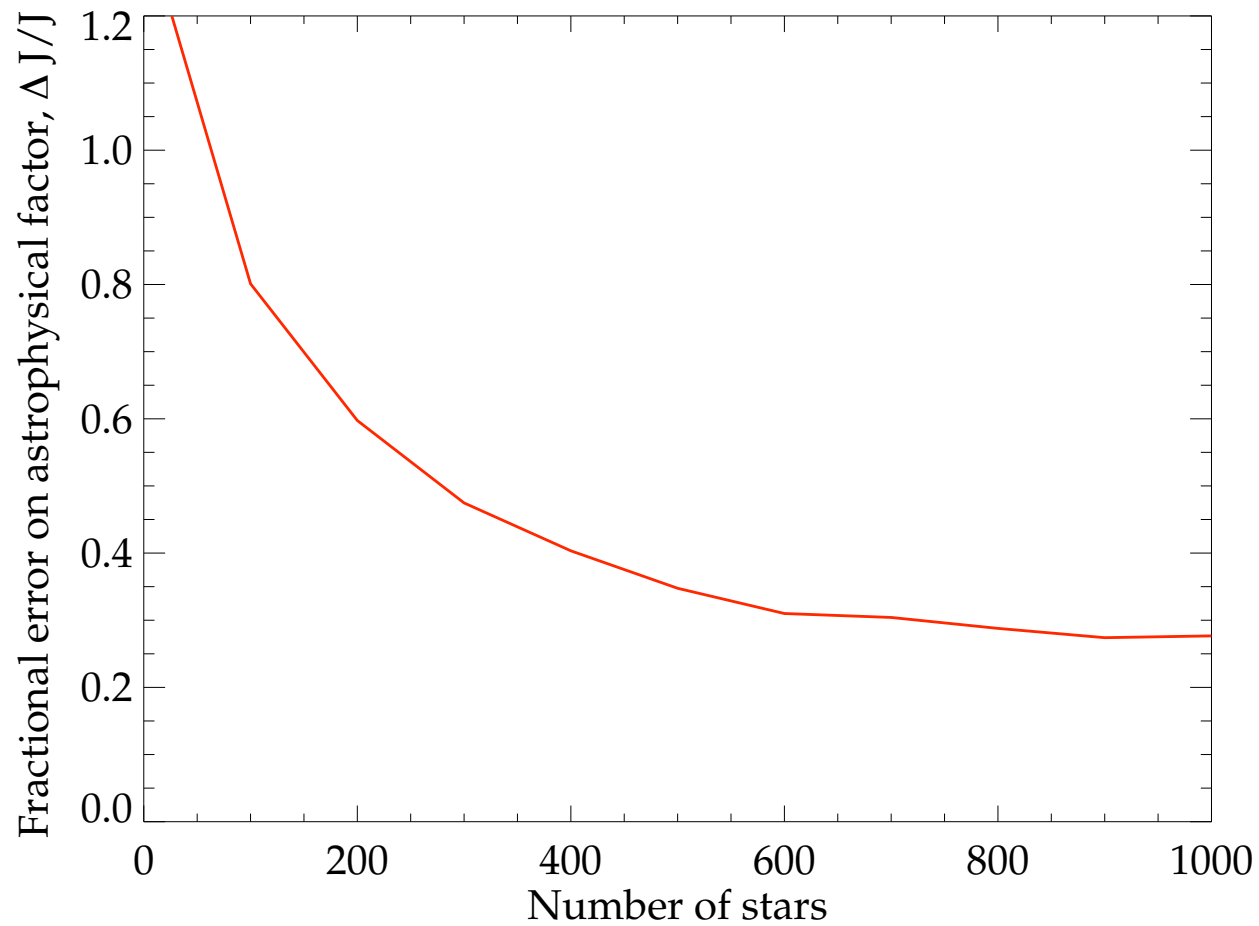
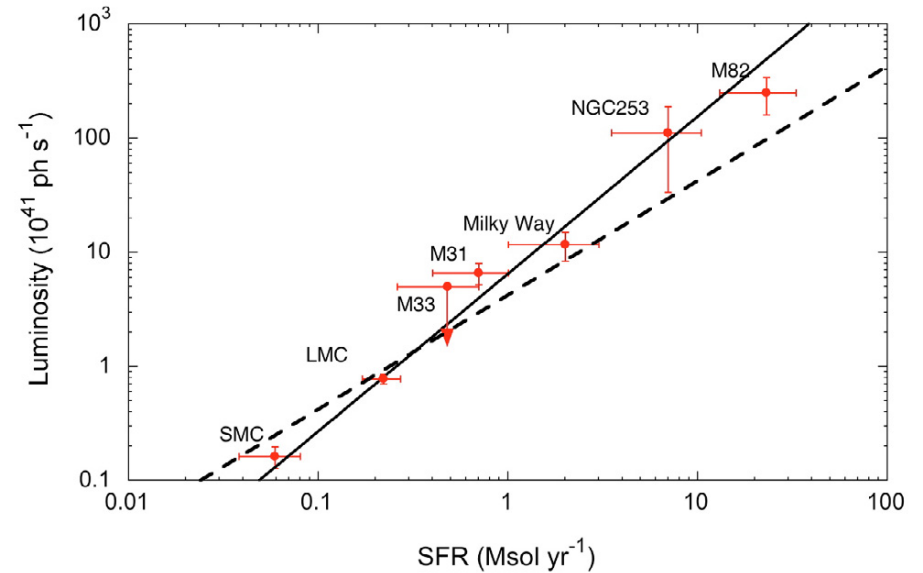
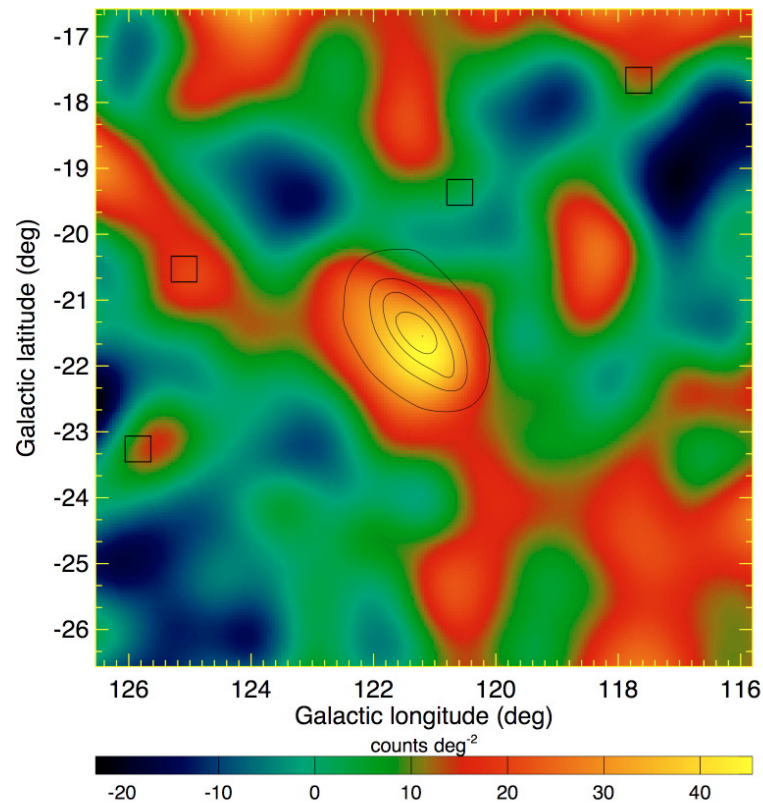


Fig. Credits: S. Funk & J. Hinton

Future constraints



Fermi-LAT detection of Local Group Galaxies

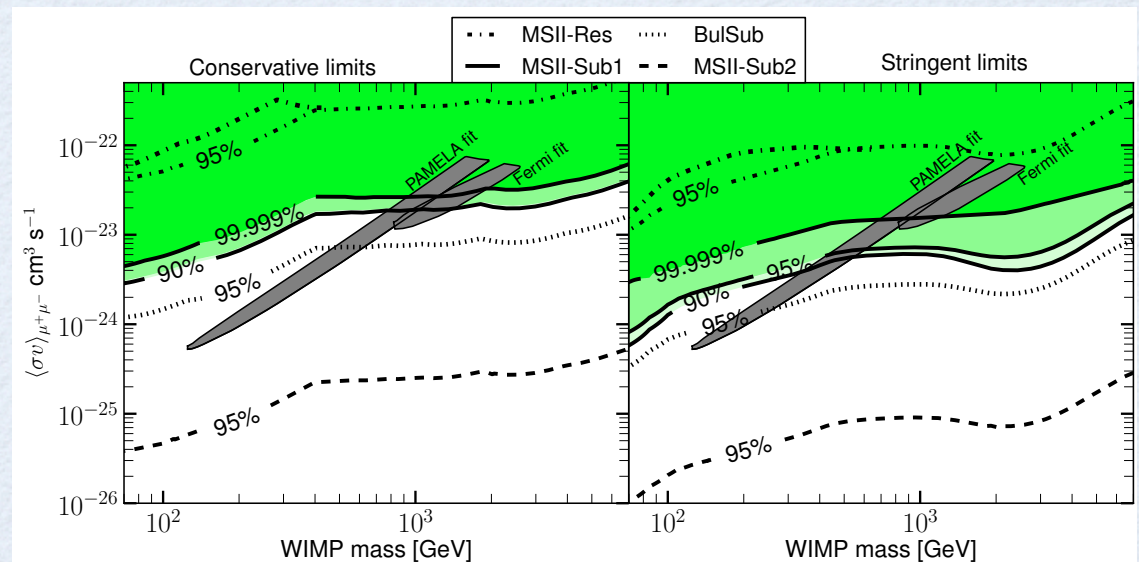
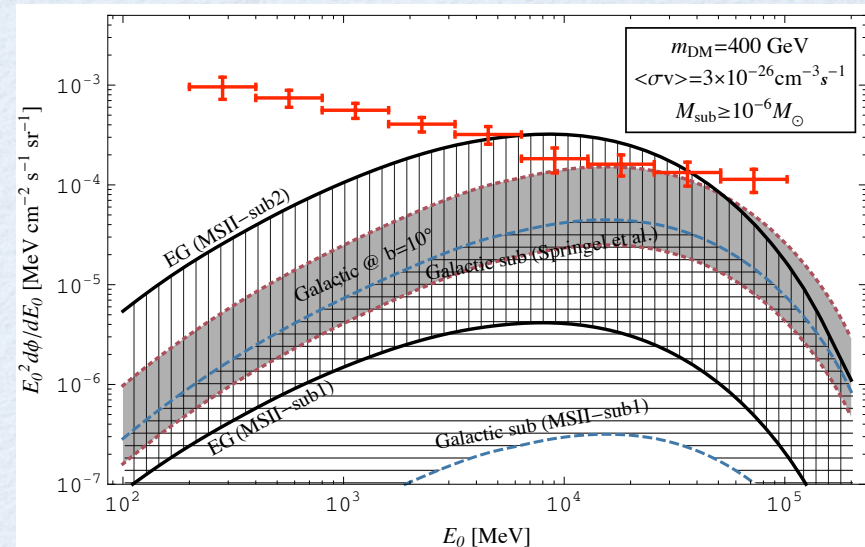


Search for dark subhalos

- ▶ Idea: Search for objects that only shine because of dark matter annihilation
- ▶ Some satellites could be within a few kpc of the Sun, and their extension may be resolved by the LAT
- ▶ Search criteria:
 - ▶ More than 20 degrees from Galactic plane
 - ▶ No counterpart at other wavelengths
 - ▶ Emission constant in time
 - ▶ Spatially extended: 1 degree radial extension

Cosmological WIMPs

- ▶ Cross section limits derived from measurement of power law extragalactic spectrum
- ▶ Energy range of 20-100 GeV
- ▶ Some uncertainties due to the distribution of dark matter
- ▶ Possible to exclude DM interpretation of the Fermi, Pamela electron spectrum



Outlook

- Search for WIMP dark matter is progressing rapidly
- Galactic center analysis underway
- Fermi dwarf limits getting very interesting.
 - Stacking analysis forthcoming
 - New satellites will be discovered
- just 2 years in of a (hopefully) 10 year mission